Kuroshio Penetrations into the South China Sea: Analysis of the Dynamics and Predictability

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LONG-TERM GOALS

Our ultimate goals are to understand the dynamics of the Kuroshio penetrations into the South China Sea and to develop a model of its predictability on interannual time scales.

OBJECTIVES

Our objectives are:

1. To identify the main dynamical mechanism responsible for the Kuroshio penetrations into the South China Sea as a loop current,

2. To study the relationship between the loop current penetrations and external factors such as transport and speed of the Kuroshio outside the Luzon Strait, wind stress, and also velocities induced by excited basin Rossby modes.

3. To search for evidence of multiple quasi-steady circulation states and hysteresis in the loop current evolution, which will lay a basis for a predictability model of the loop current penetrations on seasonal and interannual time scales using a dynamical system approach.

APPROACH

Our hypothesis is that the Kuroshio usually leaps across the Luzon Strait; however, during periods when its strength is substantially reduced, it may penetrate into the South China Sea due to the beta effect (Sheremet, 2001). More importantly the flow can be in multiple quasi-steady states and the transition between them involves a hysteresis (dependence on prior evolution). We have been testing this hypothesis with a combination of (1) a theoretical analysis of the flow dynamics in the Luzon Strait, (2) an analysis of historical observations of the Kuroshio, and (3) an analysis of the output in the North Pacific Ocean Nowcast/Forecast System (NPACNFS) developed at the Naval Research Laboratory at Stennis Space Center, focusing on the area near the Luzon Strait and on the northern part of the South China Sea.

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14. ABSTRACT
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15. SUBJECT TERMS

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WORK COMPLETED

In the past few months we analyzed the current measurements (Shipboard ADCP and moored array) collected in Luzon Strait (Tang, 2002) and compared them with the prediction of our theoretical model (Sheremet, 2001).

We looked at historical data on the Kuroshio penetrations into the South China Sea, the results of the past numerical simulations conducted by Metzger and Hurlburt (2001) using the Navy Layered Ocean Model (NLOM) and connected them with the estimates of the circulation strength in the Northern Pacific subtropical gyre inferred from the Kuroshio Path Index (Qui and Miao, 2000; and Qui, *pers. comm*.).

However, we primarily concentrated on analyzing the output of NPACNFS provided by D. Ko. We worked with 5-day averaged flow fields looking for the evidence of connections between the various dynamical processes occurring in the North Pacific basin, the Kuroshio strength east off Luzon and Taiwan, and loop current penetrations into the South China Sea. To suppress short time scale variability we employed the method of relaxation to a running mean (Sheremet, 2003).

We also worked with T. Duda on the effect of the Kuroshio penetrations on propagation of internal solitons generated in the Luzon Strait and observed during ASIAEX.

The results of this research have been presented at the Ocean Science Meeting (Sheremet, 2002), a seminar at the University of Rhode Island in July 2002 and at the "Z-coordinate Ocean Modeling Meeting'' at M.I.T., 21-23 August, 2002.

RESULTS

The comparison of observed time-averaged flow fields in the Luzon Strait collected from shipboard ADCP (Tang, 2002) with the numerical solutions based on our theoretical model (Sheremet, 2001) allows us to validate the main hypothesis that the flow inside the strait is governed by the balance between the beta effect and inertia. The model correctly predicts not only the shape of the main intrusion, but also the existence of small-scale features such as the flow separation and recirculation east off Taiwan.

Analysis of historical data on the Kuroshio penetrations and comparison with the Kuroshio Path Index (Qui and Miao, 2000) allows us to conclude that on decadal time scales there are definitely two distinct flow paths leaping and penetrating which are connected to the strength of the circulation in the subtropical North Pacific gyre and hence with the transport of Kuroshio.

It was proposed earlier that the Kuroshio penetrations on the seasonal time scales could be connected to the strength of monsoon winds in the vicinity of Luzon Strait (Farris and Wimbush, 1995). Our analysis of the output of the NPACNFS suggests that the penetrations may be related to the arrival of

long Rossby waves generated in the North Pacific interior. Such a signal is well seen in the phase propagation diagram of the surface elevation along the latitude of Luzon Strait (Figure 1).

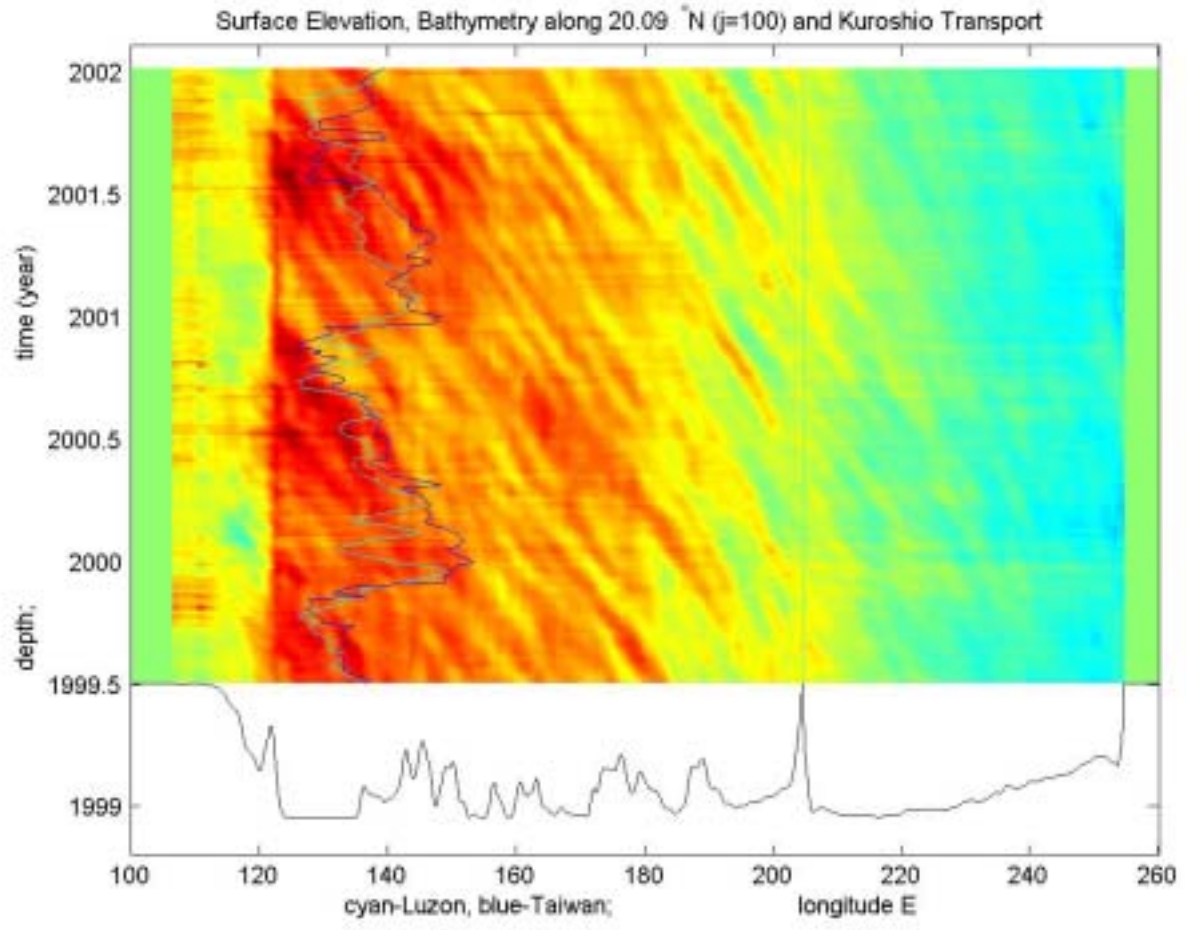

Figure 1: The phase propagation diagram of the surface elevation along the latitude of Luzon Strait (20N). The x-axis is longitude and the y-axis is time in years. Overlapped are the Kuroshio transport variations versus time at two locations: east off Luzon Island (cyan) and east of Taiwan Island (blue). In the lower portion of the figure the bottom topography is overlapped. Significant decreases in transport coincide with the reflection of Rossby wave packets (dark red) in fall and winter. The data are from NPACNFS runs spanning the period from July 1999 through January 2002.

The reflection of Rossby waves from the western boundary causes fluctuations in the Kuroshio transport and velocity. Significant weakening of the Kuroshio due to Rossby wave reflection occurs during fall and winter, coinciding with the monsoon season and penetrations. Individual penetration events appear well correlated with the decrease of the Kuroshio transport east of Luzon Island (Figure 2).

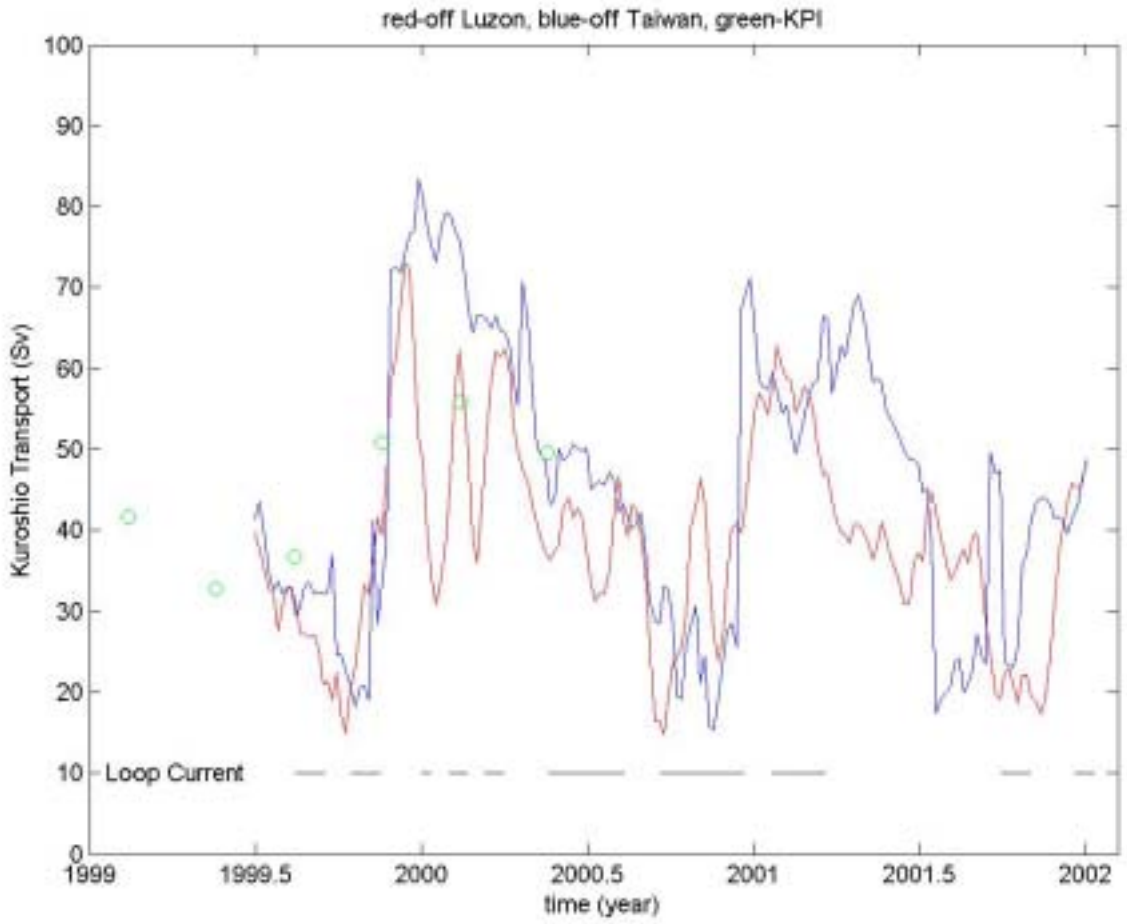

Figure 2: The Kuroshio transport fluctuations at two localities: east of Luzon Island (red) and East off Taiwan Island (blue) caused by reflection of Rossby waves. The green circles indicate the Kuroshio Path Index based on observations off Japan. The periods the Kuroshio penetrations and Loop Current development are indicated by horizontal segments; they largely coincide with the decreased transport off Luzon Island, upstream of the strait.

IMPACT/APPLICATIONS

Our results are helping in the interpretation of hydrographic observations of the jet impinging on the shelf in the Northern South China Sea during ASIAEX. They are also relevant to other areas where the boundary current penetrates into a marginal basin as in the Gulf of Mexico, or in the Gulf of Maine.

TRANSITIONS

We are actively communicating the results with Glen Gawarkiewicz, Tim Duda (WHOI), and D. Ko (NRL, Stennis Space Center) to help interpret observations during ASIAEX and to diagnose the output of the NPACNFS.

RELATED PROJECTS

We also analyzed a similar phenomenon of a boundary current leaping across the gap in the context of a shelf-break current in the Georges Bank area. It was found that the loop current penetrations are caused by weakening of the shelf-break front as expressed by its density difference (Cho *et al*., 2002).

REFERENCES

Farris, A., and M. Wimbush, 1996: Wind-induced Kuroshio intrusion into the South China Sea. *J. Oceanogr.*, **52**, 771-784.

Metzger, J.E. and H.E. Hurlburt, 2001: The nondeterministic nature of Kuroshio penetration and eddie shedding in the South China Sea. *J. Phys. Oceanogr.,* **31**, 1712-1732.

Qiu, B. and W. Miao, 2000: Kuroshio path variations south of Japan: Bimodality as a self-sustained internal oscillation. *J. Phys. Oceanogr*., **30**, 2124-2137.

Tang, T. Y., W.-D. Liang and W.-S. Chuang, 2002: Kuroshio Intrusions in Northern South China Sea. *Eos Trans. AGU,* **83(4)**, Ocean Science Meet. Suppl., Abstract OS22N-01.

PUBLICATIONS

Cho, Y.-K., R. Beardsley and V. A. Sheremet, 2002: On the cause of the Scotian Shelf Water crossovers. *Geophys. Res. Letters*, in press.

Sheremet, V. A., 2001: Hysteresis of a western boundary current leaping across a gap. J. *Phys. Oceanogr*., **31**, 1247-1259.

Sheremet, V. A., 2002: Hysteresis of a western boundary current leaping across a gap with application to the Kuroshio penetrations into the South China Sea. *Eos Trans. AGU,* **83(4)**, Ocean Science Meet. Suppl., Abstract OS22N-04.

Sheremet, V. A., 2003: A method of finding unstable steady solutions by forward time integration: relaxation to a running mean. *Ocean Modelling*, **5**, 77-89, in press.